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DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

TWIN CITIES MINING RESEARCH CENTER

Walter E. Lewis, Research Director

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MULTIDISCIPLINARY RESEARCH LEADING TO
UTILIZATION OF EXTRATERRESTRIAL RESOURCES

Quarterly Status Report
July 1, 1969 to October 1, 1969

U.S. Bureau of Mines NASA Program of Multidisciplinary Research Leading to Utilization of Extraterrestrial Resources

QUARTERLY STATUS REPORT July 1, 1969 to October 1, 1969

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STATUS REPORT FIRST QUARTER FISCAL YEAR 1970

U.S. Bureau of Mines NASA Program of Multidisciplinary Research
Leading to Utilization of Extraterrestrial Resources

October 1, 1969

Task title:	Background analysis and coordination	
Investigator:	Thomas C. Atchison, Program Manager	
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota	
Date begun:	April 1965	To be completed: Continuing
Personnel:	Thomas C. Atchison, Supervisory Research Physicist Other Bureau personnel, as assigned	

PROGRESS REPORT

Objective

The objective of the program is to help provide basic scientific and engineering knowledge needed to use extraterrestrial mineral resources in support of future space missions. Under this component, background and supporting studies and coordinating and liaison activities for the program are carried out.

Progress During the First Quarter

The initial phase of the Bureau's program beginning with fiscal year 1966 consisted of a period of background study and task definition carried out by a small interdisciplinary core group at the Twin Cities Mining Research Center. The second phase, largely completed by the end of fiscal year 1969, comprised sixteen closely related research tasks conducted at seven Bureau research centers. Results of these tasks were presented in the annual status reports for fiscal years 1967, 1968, and 1969 and published in Bureau and NASA reports and scientific journals. Reports related to completed tasks that have not yet been published are listed below. The present phase of the program, beginning with the current fiscal year and planned for a duration of 2 years, is composed of seven research tasks at four Bureau centers. These tasks represent an extension and refinement of some of the previous research tasks with major emphasis on the more basic studies of material properties and behavior in simulated lunar environment.

During the past quarter, information from preliminary examination of the returned lunar samples at the Houston laboratory was obtained, studied, and distributed to the task investigators. A set of black and white photographs and color transparencies from the Apollo 11 mission was obtained from NASA for examination. The set included all the pictures of the lunar surface taken from orbit and during the landing. New arrangements were made with NASA's publications information office for obtaining more specific coverage of our interest areas in their report distribution and bibliographic services.

T. C. Atchison attended a meeting of the Planning Committee of the Working Group on Extraterrestrial Resources at NASA Headquarters in Washington, D. C. in September. The next annual meeting of the Working Group will be held in the fall of 1970 at the Manned Spacecraft Center in Houston, Tex. and will highlight the possibilities and problems of utilizing lunar permafrost. A meeting of the Subgroup on Mining and Processing is planned in mid-January at Minneapolis.

Status of Manuscripts

Strengths of Sulfur-Basalt Concretes by L. J. Crow and R. C. Bates was submitted for publication as a Bureau of Mines Report of Investigations.

Carbothermal Reduction of Liquid Siliceous Minerals in Vacuum by S. E. Khalafalla and L. A. Haas was submitted to the Journal of High Temperature Science.

Mineral Decomposition in High Vacuum by R. L. Carpenter was prepared for presentation at the Pacific Coast Regional Meeting of the American Ceramic Society at Seattle, Wash., October 15-17, 1969, and is being expanded for publication as a Bureau of Mines Report of Investigations.

Factors Related to Mineral Separation in a Vacuum by F. Fraas was submitted for publication as a Bureau of Mines Report of Investigations.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1970

Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Surface properties of rock in simulated lunar environment
Investigator:	Wallace W. Roepke, Project Leader
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	April 1966 To be completed: June 1971
Personnel:	William H. Engelmann, Supervisory Research Chemist Wallace W. Roepke, Principal Vacuum Specialist Kelly C. Strebig, Mining Engineer Robert L. Schmidt, Mining Engineer Kenneth G. Pung, Physical Science Technician James R. Blair, Physical Science Technician

PROGRESS REPORT

Objective

The objective of this task is to study the surface properties of rocks and minerals in a simulated lunar environment. The study includes friction of metal-mineral pairs, drilling in rock, and shear testing of particulate mineral and rock materials.

Progress During the First Quarter

This task was realigned at the start of the new fiscal year to include three major phases (friction studies, drilling studies, and particulate shear studies), one minor phase (vapor coating support), and overall scheduling of experimental work in ultrahigh vacuum (UHV) for all of the basic NASA studies. Completion of the study of chemical reactivity of freshly formed surfaces, planned for later this fiscal year, will also be reported under this task.

Delivery of a radiometer ordered at the beginning of the quarter was delayed longer than anticipated forcing this task and the task under Thermal Fragmentation to delay testing affected by this equipment. A major delay in delivery of another UHV system for this task will cause the UHV friction tests to be recessed during the second quarter. However, analysis of data obtained during the first quarter will continue. The recess in the friction testing will occur because the present UHV system will be required for the UHV drilling studies.

UHV Friction Studies

The friction studies on metal-mineral pairs have been accelerated appreciably this quarter through use of a new data recording and processing system. Previously the outputs of the load-cell bridge and friction-force bridge were recorded separately on an oscillograph and the kinetic coefficient of friction was calculated by dividing the tangential force by the normal force at sufficient points to obtain a good average value. The outputs from these bridges now go into operational amplifiers and a divider circuit that provide a recorder with a direct measurement of the coefficient of friction at any instant during a test. The average kinetic coefficient of friction for a given test is found by using a planimeter to measure the area under the recorded curve. We have been greatly assisted in the analysis of the data by Mr. Ernest Bukofzer, who has done the initial planimetry.

The following materials have been tested in ambient atmospheric conditions this quarter: pyroxene, magnetite, andesine, white feldspar, pink feldspar, labradorite, basalt, dacite, quartz (reference sample), and polished stainless steel (reference sample). These materials have all been tested at 50-, 100-, and 150-gram normal loads. Basalt, dacite, and the stainless steel reference samples have also been tested under dry atmospheric conditions and UHV with and without laser surface cleaning. Preliminary results indicate that the basalt will have a coefficient of friction greater than 0.4 in UHV before surface cleaning, while the value for the dacite under the same conditions will lie between 0.2 and 0.3.

Surface examination with the scanning electron microscope (SEM) has been used for some preliminary investigations of laser damage on pyroxene and probe damage on basalt and quartz. Initial difficulty in observing a track on quartz occurred because of operational unfamiliarity with the SEM. As we become more familiar with the instrument, this problem should not occur. A track on a sample of basalt tested with a 150-gram load in air has been easily observed. Analysis of the probe track with the SEM permits determination of the apparent area of contact. From the apparent area of contact and the friction test results, one can calculate shear strength, ploughing force, yield pressure, and hardness.

UHV Drilling Studies

Preparations for drilling in UHV have continued during this quarter. The vacuum drill apparatus has been successfully tested under atmospheric conditions. A 1/2-inch diameter hole was bored to a depth of 1-1/2 inches in dacite rock at a rate of 1/2 inch per minute. High-speed movies were made and continuous recordings of torque and thrust (load) were taken. The apparatus operated smoothly with a minimum of vibration. The mechanical cuttings removal system also performed satisfactorily.

Prior to making the tests in the UHV chamber, some time has been spent improving the drill apparatus and refining the associated instrumentation. A more accurate torque sensor has been ordered for use with the system. The new sensor uses an optical pickup with a built-in tachometer for continuous recording of motor rpm. The elimination of slip rings will allow a much better signal-to-noise ratio for the recorded data. The sample holding area of the drill rig has been modified to accept a turntable type base for the sample. This will allow remote rotation of the sample between drill runs under UHV so that a maximum of five holes can be bored for each evacuation of the chamber.

UHV Particulate Shear Studies

This work is being performed in cooperation with the Spokane Mining Research Laboratory and represents that portion of their work for which they require UHV facilities. The coinvestigator carrying on the work at the Twin Cities Mining Research Center is Mr. Kelly Strebig. The work includes adaptation of the vane shear apparatus designed at Spokane for use in UHV, construction and calibration of the modified apparatus, and testing in UHV on basalt and dacite particulate materials.

The vane shear tester design has been made compatible with the UHV system and has been adapted to the drill stem on the drill apparatus. The drill apparatus makes an ideal rigid test platform for the fine particle work. Construction of the shear tester has been completed and associated instrumentation designed during this quarter. Bench testing of the equipment will be done in the next quarter.

SEM Vapor Coating and Other Technical Support

This phase of the work includes support to the SEM in vapor coating of samples and technical support to other areas involving UHV and related techniques. Samples have been prepared for SEM work as needed by different Center laboratories. Assistance was given on UHV problems in the work under the Rock Physics task, and scheduling of UHV equipment for all of the tasks has been planned on a coordinated basis for the current fiscal year. Consultation on problems involving the use of mass spectrometers was provided to the Twin Cities Metallurgy Research Center.

Status of Manuscripts

Mass Spectrometer Studies of Outgassing from Simulated Lunar Materials in Ultrahigh Vacuum by W. W. Roepke and C. W. Schultz is being revised for publication in the Journal of the American Vacuum Society.

Friction Tests in Simulated Lunar Vacuum by W. W. Roepke was submitted to NASA for publication in the Proceedings of the Seventh Annual Meeting of the Working Group on Extraterrestrial Resources.

Developing a Lunar Drill: A 1969 Status Report by R. L. Schmidt was submitted to NASA for publication in the Proceedings of the Seventh Annual Meeting of the Working Group on Extraterrestrial Resources.

IR-Visible Window Composite for UHV by W. W. Roepke was submitted for publication in the Review of Scientific Instruments.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1970

Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Rock failure processes and strength and elastic properties in simulated lunar environment
Investigator:	Peter G. Chamberlain, Project Leader
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	June 1966 To be completed: June 1971
Personnel:	Egons R. Podnieks, Supervisory Mechanical Engineer Robert J. Willard, Geologist Thomas R. Bur, Geophysicist Richard E. Thill, Geophysicist Peter G. Chamberlain, Geophysicist Laxman S. Sunda, Mining Engineer Rollie C. Rosenquist, Engineering Technician

PROGRESS REPORT

Objective

The objective of this project is to study the effect of simulated lunar environment on rock deformation and failure processes at the macrostructural and the microstructural level by means of petrographic and scanning electron microscopy. Rock strength and elastic properties of simulated lunar rocks will be determined in ultrahigh vacuum at temperatures over the lunar surface temperature range.

Progress During the First Quarter

Compression Tests in Ultrahigh Vacuum

Compression tests on tuff specimens in ultrahigh vacuum (high 10^{-11} torr to low 10^{-9} torr range) were completed. Pressure and degassing data were recorded for each test in accordance with procedures established during preliminary tests described in previous progress reports.

Several tests were performed on tuff at atmospheric pressure to establish a comparative baseline for compression properties obtained in ultrahigh vacuum. Tests were conducted on specimens in dry nitrogen environment without prior exposure to vacuum, and on specimens evacuated identically to those tested in ultrahigh vacuum and then flooded with dry nitrogen for the test.

Anisotropy Studies

Pulse velocity and attenuation symmetry patterns determined for the suite of simulated lunar rocks last fiscal year have been analyzed in more detail (table 1). The attenuation symmetry was the same as the elastic symmetry (determined from the velocity pattern) for most of the rocks, dunite and tuff being exceptions. The difference in the elastic and attenuation symmetry of these two rocks indicates that the major controlling subfabric of one property possesses a symmetry system in the case of the dunite, or an orientation in the case of the tuff, differing from that of the major controlling subfabric of the other property. This difference will be of importance during future attempts to correlate either elastic or attenuation variations with variations in other properties such as tensile or compressive strength.

TABLE 1. - Elastic and attenuation symmetries of simulated lunar rock

Rock	Elasticity		Attenuation	
	System[1]	Anisotropy[2] (percent)	System[1]	Anisotropy[2] (percent)
Pumice	0	108	0 or TI	155
Vesicular basalt #3	0	43	0	155
Rhyolite	0	36	0	100
Serpentinite	0	27	0	185
Dacite	0	27	0	85
Semiwelded tuff	0	25	0	100
Dunite	TI	15	0	65
Altered rhyolite	0	13	0 or M	100
Granodiorite	0	10	0	65
Vesicular basalt #1	0	6.7	0	65
Duluth gabbro	0	3.3	0	35
Obsidian	TI	.7	([3])	([3])
Tholeiitic basalt	I	0	([3])	([3])
Vesicular basalt #2	H	-	-	-

[1]H = heterogeneous, I = isotropic, M = monoclinic, 0 = orthorhombic, TI = transversely isotropic.

[2]Calculated from $2(V_{max} - V_{min})/(V_{max} + V_{min})$ for elasticity and a similar equation for attenuation.

[3]Resolution was not good enough to obtain these values.

Fabric Analysis

Rock fabric is being compared with pulse velocity symmetry patterns previously obtained from spheres of the simulated lunar rocks. A slab has been cut from each of the spheres along the high-low velocity plane established from the pulse velocity measurements. Six of these slabs have been ground into thin sections. Preliminary analysis of these sections reveals that for each rock there exists a fabric anisotropy which corresponds with the high and low velocity directions. In two of the rocks, pumice and vesicular basalt, the degree of the fabric anisotropy is approximately proportional to the velocity anisotropy.

Results of an earlier study of the pumice were included in a paper titled "Correlation of Longitudinal Velocity Variation with Rock Fabric" by R. E. Thill, R. J. Willard, and T. R. Bur, published in the September 15 issue of the Journal of Geophysical Research (v. 74, No. 20, pp. 4897-4909). Fabric data from the study of the effect of moisture on fracture morphology in dacite were reexamined and a draft of a report on the results is about 50 percent completed.

General

Beginning with this fiscal year Mr. Peter G. Chamberlain has assumed the duties of principal investigator for this research task.

Status of Manuscripts

Environmental Effects on Rock Properties by E. R. Podnieks, P. G. Chamberlain, and R. E. Thill has been submitted for publication in the Proceedings of the Tenth Symposium on Rock Mechanics held at the University of Texas in May 1968.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1970

Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Thermal fragmentation and thermophysical and optical properties in simulated lunar environment
Investigator:	David P. Lindroth, Project Leader
Location	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	July 1969 To be completed: June 1971
Personnel:	Joseph M. Pugliese, Supervisory Geophysicist David P. Lindroth, Physicist Walter G. Krawza, Engineering Technician

PROGRESS REPORT

Objective

The objective of this work is to study the problems of thermal fragmentation in lunar environment. Through the use of nondestructive testing and remote sensing technology, the thermophysical properties of simulated lunar rocks are to be determined as a function of temperature and pressure over the lunar environment range. Also, the optical properties of absorptance, reflectance, transmittance, and the absorption coefficient are to be determined as a function of wavelength and temperature.

Progress During the First Quarter

The first phase of this task is devoted to the use of nondestructive testing and remote sensing technology for the determination of material properties. With the advent of laser technology a large portion of the electromagnetic spectrum is available. Since this opens the door to a broad spectrum of energy sources, a determination of optical properties (emphasis on absorptance and absorption coefficient) as a function of wavelength and temperature is a logical starting point. This work is being initiated by a literature search on optical properties. The determination of the optical properties will permit the selection of optimal energy sources for fragmenting rocks by electromagnetic radiation. The optical property information then, will lead to fragmentation studies in vacuo during fiscal year 1961.

The literature search will also significantly complement the work with the flash method being developed for the measurement of thermophysical properties, because knowledge of the optical properties of the rock material will eliminate the need for special surface preparation such as black coatings thus improving the precision of the measurements. Knowledge of the optical properties can lead eventually to in situ determination of the thermophysical properties.

The property measurement techniques developed under this project will be capable of being adapted to other simulated environments. A small portion of time (approximately 15 percent) will be devoted to other areas, such as frothing or casting basalt, laser drilling or coring techniques, and interferometric holography.

During the first quarter a literature search was conducted to obtain data on the absorptance, absorption coefficient, transmittance, and reflectance as a function of wavelength and temperature for as many rock types as possible. The majority of the data found to date covers the wavelength range from 1 to 30 micrometers. Data on the variation of absorptance as a function of temperature are scarce. Most of the values are for minerals and have been calculated from reflectance spectra obtained at ambient temperature.

Initial design work has been completed on a multispecimen sample holder to be used for thermal property measurements in the ultrahigh vacuum chamber. Planned radiometer work has been delayed because our infrared radiometer did not arrive until the middle of September.

Dr. Thirumalai and Mr. Demou continued with the remaining experimental work from the previous feasibility task. The final runs in a series of tests using laser impingement of a known energy density on disk specimens of basalt, granodiorite, obsidian, and quartzite in vacuum (10^{-6} torr) and atmosphere were completed. Three samples of each rock type in each environment were used. Approximate melting temperatures were noted by use of an optical pyrometer. Samples of basalt were cut to provide a cross section of the damaged area and photomicrographs were obtained with the scanning electron microscope in cooperation with R. J. Willard. The micrographs show that the vacuum specimens incurred a greater depth of damage than the atmospheric specimens for the same thermal energy input.

Surface layer thermal expansion studies of quartzite, granodiorite, and obsidian from room temperature up to 315° C using high temperature strain gages cemented with a spray of molten alumina (Rokide process) were nearly completed. A total of 16 specimens were subjected to two successive cycles between room temperature and 315° C to determine the surface layer expansion and hysteresis effects in atmosphere and vacuum. The results are being analyzed.

Status of Manuscripts

Dielectric Constants and Dissipation Factors for Fourteen Rock Types Between 20 and 100 Megahertz by R. E. Griffin is under preparation as a journal article.

Thermal Expansion Measurements of Simulated Lunar Rocks by R. E. Griffin and S. G. Demou is under preparation as a journal article.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1970

Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Use of explosives on the Moon
Investigator:	Richard W. Watson, Project Coordinator, Explosives Research
Location:	Safety Research Center Pittsburgh, Pennsylvania
Date begun:	July 1966 To be completed: June 1971
Personnel:	Richard W. Watson, Research Physicist Charles R. Summers, Research Physicist John J. Mahoney, Laboratory Technician Elva M. Guastini, Explosives Equipment Operator

PROGRESS REPORT

Objective

The objective is to develop fundamental knowledge relating to the hazards of the use of chemical explosives in the lunar environment, in particular, an environment characterized by high vacuum, extreme temperature cycling, and a flux of small hypervelocity particles.

Progress During the First Quarter

During this fiscal year effort will be concentrated on experimental study of the expansion of explosive detonation products in a vacuum. Small-scale experiments will continue using techniques developed last year with expendable glass chambers at pressures as low as 10^{-7} torr. Installation of a large-scale facility capable of operating at 10^{-4} torr or less will be completed.

This task was largely inactive during the first quarter because of reorganization and redefinition of the Bureau's research at Pittsburgh. The Explosives Research Center was combined with major elements of the Health and Safety Research and Testing Center to form the Pittsburgh Safety Research Center. Dr. Robert W. Van Dolah who had headed the Explosives Research Center is Research Director of the new Center. Richard W. Watson is now the principal investigator for this research task. Some progress was made in developing the high vacuum facility for large-scale studies.

Status of Manuscripts

None scheduled for the first quarter.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1970

Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Effect of lunar environment on behavior of fine particles
Investigator:	David E. Nicholson, Project Leader
Location:	Spokane Mining Research Laboratory Spokane, Washington
Date begun:	April 1966 To be completed: June 1971
Personnel:	David E. Nicholson, Mining Engineer William G. Pariseau, Civil Engineer Kelly C. Strebig, Mining Engineer (Twin Cities) Robert W. Carnes, Engineering Technician

PROGRESS REPORT

Objective

The objective is to determine the frictional and cohesive properties of simulated lunar rock powders which may influence the handling and transportation of fine particle materials in the lunar environment.

Progress During the First Quarter

A torsional vane shear apparatus was built at Spokane for preliminary shear tests on simulated lunar powder, under normal dry atmosphere conditions. These tests are planned to precede similar tests, conducted with the same type of torsional device, in the Twin Cities ultrahigh vacuum chamber during the third quarter. The vane drive mechanism to be used with the apparatus has not been delivered from the manufacturer, so that the calibration of the torque head and rotation displacement measurement have not been completed.

Planned construction of a special type of direct-shear device has been deferred because of difficulties in converting commercial types of direct-shear devices to low normal and shear loads, representative of one-sixth lunar gravity.

Continued background literature study of special adaptations of Mohr-Coulomb theory has provided additional support for the treatment of soil shear under preconsolidation loads in the manner proposed in our fiscal year 1969 annual report. Similar previous work is well documented by Tschebotarioff in "Soil Mechanics, Foundation and Earth Structures," McGraw-Hill Book Co., 1951, pp. 154-156. The Krey-Tiedemann criterion for soil failure treats the cohesion of the soil as a function of consolidation load. In most cases the consolidation load is applied normally.

A request for the preparation of a large sample of simulated lunar soil using Little Lake basalt in our crushing and sizing circuit was received from the Geological Survey in Flagstaff, Ariz. A cost estimate for preparation of the material to simulate the Apollo 11 core samples has been prepared and submitted to the Survey.

Status of Manuscripts

None scheduled for this quarter.

STATUS REPORT FIRST QUARTER FISCAL YEAR 1970

Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Electrowinning of oxygen from silicate rocks		
Investigator:	Donald G. Kesterke, Project Coordinator		
Location:	Reno Metallurgy Research Center Reno, Nevada		
Date begun:	June 1966	To be completed:	May 1970
Personnel:	Donald G. Kesterke, Metallurgist Freddy B. Holloway, Physical Science Technician		

PROGRESS REPORT

Objective

The objective is to determine the feasibility of obtaining elemental oxygen by electrolysis of silicate-bearing materials, as one phase of multidisciplinary research efforts to develop basic knowledge for using lunar resources in support of space missions.

Progress During the First Quarter

Objectives for the year are to continue studies to develop an efficient procedure for electrowinning free oxygen from silicate-bearing materials. Evaluation of various electrolyte compositions will continue in efforts to reduce the amount of fluxing materials required for low-melting, electrically conductive baths.

Studies will be initiated to determine the physical characteristics of baths containing silicates having the approximate composition of lunar surface materials obtained during the Apollo program. Modification in cell design will be made to isolate the anode from the cathode deposit by means of a boron nitride barrier. Operating characteristics of this cell will be studied in experiments of extended duration.

Methods will be evaluated for collecting the gases evolved at the anode. This will permit quantitative determination of the amount of oxygen produced, from which the cell efficiency will be calculated. Recommendations regarding continuation or reorientation of the research effort will be made based on the data obtained.

The work during this quarter was aimed at determining the relative physical characteristics of selected silicate-fluoride mixtures in efforts to find a workable electrolyte which contains a lower percentage of fluxing materials than was required in previously used baths. Studies were made of the relative electrical conductivity of these mixtures at various temperatures. The LiF content of each mixture was 25 weight-percent, while the BaF_2 content ranged from 0 to 35 weight-percent, and the silicate content ranged from 75 to 40 weight-percent. Results of these experiments are presented in the following table in which the relative electrical conductivity is expressed as the amperage-to-voltage ratio.

Bath composition weight-percent			Amperage-to-voltage ratio		
Silicate	BaF_2	LiF	1,050° C	1,100° C	1,150° C
75	0	25	0.8	1.2	2.2
70	5	25	1.2	2.1	2.6
65	10	25	1.2	2.4	3.3
60	15	25	1.5	2.6	3.7
55	20	25	1.9	3.2	3.7
50	25	25	1.9	3.3	3.6
45	30	25	1.9	3.0	3.6
40	35	25	1.6	3.7	4.2

These results show that the conductivity decreased significantly as the silicate content of the melts was increased above 60 weight-percent. In subsequent experiments, electrolysis will be conducted in the mixtures containing from 40 to 60 weight-percent silicate to determine which electrolyte provides the best cell performance with regard to oxygen production.

Status of Manuscripts

Electrowinning of Oxygen from Silicate Rocks by Donald G. Kesterke was submitted to NASA for publication in the Proceedings of the Seventh Annual Meeting of the Working Group on Extraterrestrial Resources.